INFRASTRUCTURE DEVELOPMENT AND NUCLEAR COMPETITIVENESS: INITIAL RESULTS OF AN IAEA RESEARCH PROJECT

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ABSTRACT

The paper presents initial results from an IAEA Co-ordinated Research Project (CRP) entitled "Impact of Infrastructural Requirements on the Competitiveness of Nuclear Power." This is a three-year CRP, begun in 1999, aimed at better understanding infrastructure requirements for various energy supply chains and their impact on economic competitiveness. Research teams from Bulgaria, China, India, Kazakhstan, Pakistan, Russia, and Turkey will model their countries' energy systems over a planning horizon of approximately 30 years. Each will define a reference scenario and up to ten variations reflecting alternative government policies, energy technology costs, and energy demand trajectories. The objective is to determine competitive advantages and disadvantages of nuclear power as a function of infrastructure investments. The focus is on the front- and back-end facilities throughout the energy chain that are needed to operate power plants, plus the necessary associated transportation network. Other, less tangible infrastructural components, such as regulatory and financial institutions, are discussed but not modeled.

CONTENTS

1. INTRODUCTION

Cost assessments in the power sector often focus on comparing plant generation costs, i.e., the sum of capital, O&M, and fuel costs. Fuel costs can account for 40-70% of levelized generation costs in fossil fuel power plants and for 5-25% of levelized generation costs in nuclear plants (IEA/NEA, 1998). Thus fuel cost projections can have a significant impact on the estimation of generation costs for competing alternatives. Estimates usually implicitly assume that the O&M and fuel costs include an infrastructural component. For example, coal costs should incorporate the costs of running coal mines (including amortized costs of initial mine development), plus the costs of processing coal and transporting it from the mine to the customer. Similarly nuclear fuel costs should include all costs incurred in the front-end of the nuclear fuel cycle – specifically uranium mining, milling, enrichment, and fuel fabrication – plus transportation costs. For nuclear power, charges for waste management that take into account infrastructural requirements in the back-end of the fuel cycle might also be incorporated into O&M or fuel costs.

The need to develop supporting energy infrastructures can have an important impact on the prospective competitiveness of alternative power plants. If the fossil fuel supply requires substantial investments – due, for example, to the depletion of coal or gas deposits – the resultant increase in generating costs for fossil fuel plants might make nuclear plants more competitive. Conversely, nuclear infrastructures at both the front- and back-ends of the fuel cycle also require investments, and to the extent that expansion is needed, nuclear fuel costs go up and competitiveness goes down. We expect the impact of infrastructural requirements on the competitiveness of nuclear power plants (NPPs) to be particularly important in countries where either nuclear expansion plans face potential infrastructural constraints or, alternatively, an existing nuclear infrastructure constitutes an important asset favoring further nuclear additions.

Theoretically, the infrastructural component of fuel costs is determined by the market, and it is up to market participants to charge prices that cover all their incurred and expected costs. In countries with established market economies and developed energy infrastructures, the market fills this role reasonably well. Very often, however, there is no reliable market experience to provide guidance on what the market price of fuels might be in five or ten years. This is the case in many developing countries, such as China, India, and Pakistan, that combine rapid anticipated energy growth with an emphasis on domestic energy resources. In these countries, the infrastructure expansion necessary to support rapid increases in generating capacity can have a significant impact on fuel costs and, consequently, on the competitiveness of alternative generation options.

Countries in economic transition, like Bulgaria and Russia, similarly lack sufficient market experience to reliably estimate an appropriate infrastructural component to include in fuel costs. Although demand growth is likely to be moderate in these countries, the need to replace aging equipment – possibly with different types of power plants (e.g., coal with nuclear or gas) – again raises the issue of properly matching changing generating capacities with infrastructural support.

Even in well-established energy markets it is also important to look carefully at projected infrastructure costs because it is not always true that fuel cost projections reliably reflect all relevant infrastructure expenditures. A closer examination of some projections, for example, reveals substantial simplifications, such as straightforward linear extrapolations, that can generate quite misleading results. Such problems are difficult to identify, however, without explicitly analyzing the energy system's infrastructural components.

2. CRP DESCRIPTION

In 1999, to gain a better understanding of infrastructure requirements for various energy supply chains and their impact on economic competitiveness, the IAEA therefore initiated a three-year Co-ordinated Research Project (CRP) on the "Impact of Infrastructural Requirements on the Competitiveness of Nuclear Power."

Within the project, national research teams model their energy systems with appropriate computer tools, including explicit representations of infrastructure requirements necessary for nuclear power and its competitors, i.e., electricity generation from coal, natural gas, oil, hydropower, and other renewable resources. The models will be used to analyze a reference baseline scenario plus up to ten variations reflecting alternative government policies, energy technology costs, and energy demand trajectories. The results should provide a basis for judging the extent to which infrastructural requirements – for both nuclear power and its competitors – increase or decrease the competitiveness of nuclear power in each country.

The IAEA selected seven countries to participate in the project. Table 1 shows key economic and energy indicators for each of the countries. As can be seen from the table, the seven countries can be divided into three groups:

- countries where the share of electricity generated by nuclear power is substantial (Bulgaria and Russia);
- countries where nuclear power has been introduced but currently supplies only a small share of national electricity (China, India, and Pakistan);
- countries with no currently operating NPPs but where nuclear power is a possible option (Kazakhstan[1] and Turkey).

[1] Kazakhstan's one nuclear power reactor was shut down in 1999.

TABLE 1. Characteristics of participating CRP countries (1998 data from IEA [2000a, 2000b])

Country	*Population, million*	*GDP/cap, thousand $US-1990*[2]	*Primary energy supply, toe/cap*	*Electricity consumption, MWh/cap*	*Share of fossil fuels in primary energy supply*	*Share of nuclear energy in generated electricity*
Countries – CRP participants:						
Bulgaria	8.3	5.0	2.4	3.9	76%	40.7%
China	1,239	3.4	0.8	0.9	78%	1.2%
India	980	1.5	0.5	0.4	57%	2.3%
Kazakhstan	15.6	3.3	2.5	2.9	98%	0.2%[3]
Pakistan	132	2.1	0.4	0.4	58%	0.6%
Russia	147	4.5	4.0	4.9	91%	12.6%
Turkey	65	7.1	1.1	1.4	85%	-
For comparison:						
EU15[4]	374	17.8	3.9	6.3	79%	34%
OECD[5]	1,101	17.9	4.6	7.8	83%	23%
US	269	26.2	8.1	13.4	86%	19%
World	5,839	5.8	1.6	2.3	79%	17%

For each of the three groups, infrastructural considerations and their impact on the competitiveness of nuclear power are somewhat different. In countries with a large share of nuclear electricity (the first of the three groups) there is a substantial focus on supporting and modernizing the nuclear infrastructure. Countries in both the second and third groups, however, are more concerned with expanding their infrastructures to match expected rapid increases in energy demand, particularly for fossil fuels. In addition, countries in the third group may have specific requirements due to the fact that they are in an initial introductory phase of nuclear development. Dividing the countries geographically, the European countries (Bulgaria and Russia) have well developed nuclear power systems on which they can concentrate their support. For the Asian countries, nuclear power is a newer option that could help substantially to meet expected rapid increases in electricity demand.

Despite their other differences, however, all seven countries rely heavily on fossil fuels. Their share of primary energy supply ranges from 57 to 98%[6]. Accordingly, the potential role of nuclear energy in decreasing dependence on fossil fuels is large, and the infrastructural costs that would be incurred by a shift to nuclear become an important factor in assessing alternative options.

[2] Gross Domestic Product (GDP) based on purchasing power parities (PPPs) as given by the IEA (2000a, 2000b).

[3] The IEA (2000a, 2000b) does not include information on nuclear generation in Kazakhstan, so 1998 data from the IAEA (1999) are used here. In 1999 nuclear generation dropped to zero with the shutdown of Kazakhstan's one NPP.

[4] Average for 15 members of the European Union (EU).

[5] Average for 29 members of the Organisation for Economic Co-operation and Development (OECD).

[6] The relatively low numbers for India and Pakistan are explained by a large share of non-commercial biomass in the energy supplies (about 40%) of these countries. Non-commercial energy is not taken into account in Table 1. Further development of the energy sector is likely to result in a substantial decrease in non-commercial energy with a corresponding increase in, most probably, fossil fuels.

Note also that in most of these countries much of the energy sector is publicly owned and managed through national utilities. Thus infrastructure investment decisions for different fuels may be made by a single institution, or at least be more closely connected than in countries with less aggregated energy industries. Similarly, energy infrastructure decisions in the seven CRP countries may be more closely tied than they are elsewhere to non-energy priorities and concerns of national decision makers.

In those countries considering energy sector deregulation, the analysis is additionally important because it can highlight the relative economic position of various energy sub-sectors as well as potential problems facing the country regardless of the form of ownership. Moves toward deregulation tend to reveal hidden subsidies or un-priced externalities, and a comprehensive analysis of energy infrastructures, as in this study, can shed additional light on such factors. This can be important for governmental agencies responsible for the deregulation of the energy sector as well as for private investors intending to enter the market who need good information about the condition of energy assets.

The CRP is scheduled for three years:

- 1999 – 2000 (1st research year): development of baseline scenarios, including baseline infrastructures, for national energy systems;
- 2000 – 2001 (2nd research year): economic analysis of alternative scenarios to identify the relationships between the level of infrastructural investments and the share of nuclear power;
- 2001 – 2002 (3rd research year): completion of economic analysis, comparison of alternative scenarios using multi-criteria analysis, and formulation of findings concerning the impact of infrastructural investment requirements on the competitiveness of nuclear power.

3. DEFINING INFRASTRUCTURE

For modeling purposes, we consider the energy infrastructure to encompass the front- and back-end facilities and transportation networks throughout the energy chain that are required to operate power plants. Since a broader definition of the term is often used, we list below infrastructural components that we have not included in the CRP modeling and the reasons that we have left them out. The list will be useful both while designing scenarios as the project moves forward and in interpreting the results at the end.

- The regulatory infrastructure – i.e., the legal and institutional framework in which the energy sector must operate, e.g., environmental protection agencies, bodies for the regulation of nuclear safety and radiation protection, etc. (IAEA, 1998; IAEA, 2000).
- The governmental infrastructure – i.e., the institutional framework for co-ordinating national and international energy development, e.g., energy ministries, nuclear ministries, etc. (IAEA, 1982; IAEA, 1998).
- The industrial infrastructure – i.e., the domestic industries needed to support national energy development. Sufficiently developed industries need to be available in a country, including in particular an adequate quality assurance system (IAEA, 1988; IAEA, 1998).

- The financial infrastructure – i.e., institutions able to allocate the financial resources necessary for energy development. Especially recently, it is important that, in addition to government support, conditions are favourable for private funding (IAEA, 1993).
- Human resources – i.e., a sufficient pool of people with the necessary talents, plus a system, including education and training, capable of producing and sustaining the necessary number of qualified workers, engineers, and scientists (IAEA, 1980; IAEA, 1986).

Although all of these are important, they are very difficult to include quantitatively in energy system models. That is the principal reason they are left out of the modeling stages of the project. Other reasons include the fact that a number of these infrastructural components have substantial general economic and social importance beyond their impact on the energy sector. They are thus difficult to analyze in an energy study independently of their broader economic and social context. Where infrastructural components are already in place – whether for energy or non-energy reasons – any changes in their economic value associated with the options examined here are unlikely to outweigh the economic impacts of the more direct infrastructural requirements that we do model. However, where many of these components are not in place, particularly in the case of a country starting nuclear development from the very beginning, such as Turkey, their impact on the competitiveness of nuclear power could be substantial. For such countries, the relevant guidelines and analyses published by the IAEA (and included in the IAEA references cited above) are an important complement to the results expected from the current project.

4. FIRST YEAR RESULTS

4.1. Key Modeling Assumptions

For each country the main deliverable for the first year is the baseline scenario – a consistent and complete scenario of energy system development under a set of well-defined assumptions that: 1) correspond to the objectives of the study; 2) are transparent; and 3) assume (usually) the most probable values of uncertain parameters.

To ensure consistency and transparency, and to make it easy to subsequently vary scenario parameters, we required first that all baseline scenarios be "computerized," i.e., that input assumptions be quantified and system parameters calculated using a quantitative energy model or set of models. The scenario should also describe a complete energy system, not just one or two sectors or regions. And it should include at least two key infrastructure categories. The first covers components *internal* to the nuclear sector (e.g., uranium mines, refining and enrichment facilities, etc). The second covers components *external* to the nuclear sector, such as gas and oil pipelines. (The ideal disaggregation of infrastructure costs would be into five categories: the electricity grid, nuclear power plants, other power plants, other nuclear infrastructure, and other non-nuclear infrastructure. In practice, each of the seven participating countries has approximated this ideal in slightly different ways.) Fig. 1 illustrates the infrastructural components of typical nuclear and non-nuclear energy chains.

Coal energy chain		**Gas energy chain**	
Chain structure	*Typical technologies*	*Chain structure*	*Typical technologies*
II Mining	- Open pit or underground mining	II Drilling and Extraction	- On- or off-shore extraction
III Transport	- Truck, train…	III Transport	- Pipeline, ship, train
IV Preparation	- Coal cleaning, coal enrichment, …	IV Processing and Storage	- Cleaning, processing, storage…
V Transport	- Truck, train…	V Transport	- Pipeline, ship, train
VI Electricity Generation	- Coal power plants	VI Electricity Generation	- Gas-fired power plants
VIA Control Technology	- Filters, precipitators, FGD/DeNox systems		
VIII Transport	- Truck, train…		
XI Waste Treatment and Disposal	- Disposal/recycling of wastes		
Nuclear energy chain – front-end		**Nuclear energy chain - electricity generation and back-end**	
Chain structure	*Typical technologies*	*Chain structure*	*Typical technologies*
II Ore Mining	- Open pit or underground mining	VC Transport	- Truck, train, ship…
IIA Milling and Leaching	- Uranium mill: processing to U_3O_8 (leaching, ion or solvent extraction)	VI Electricity Generation	- Nuclear power plants of various possible reactor types (PWR, BWR, HWR, GCR, FBR)
III Transport	- Truck, train…	VIII Transport	- Truck, train, ship… (after on-site storage)
IVA Refining and Convers. to UF6	- Dry or wet processes to UF_6	IX Reprocessing	- Reprocessing plant (for the closed fuel cycle)
VA Transport	- Truck, train… (if any)	IXA Transport	- Truck, train, ship…
IVB Uranium Enrichment	- Gaseous diffusion, centrifuge method, laser separation, other methods	X Waste Conditioning	- Conditioning (preparation for final disposal) of wastes (closed cycle) or spent fuel (open cycle)
VB Transport	- Truck, train, ship…	XI Waste Disposal	- Final disposal (deep underground repositories or other options)
IVC Fuel Fabrication	- Fuel fabrication plant (fuel elements, fuel assemblies)		

Figure 1. Structure of typical energy chains

Nearly all the countries participating in this study are in the midst of some sort of energy sector restructuring. In some countries, the process started only recently and has not yet had much effect. In others, restructuring has already affected operations in certain parts of the system, particularly the gas and power sectors. For the purposes of this study, however, ongoing restructuring does not require any special modeling approach. The CRP follows a standard approach in which the energy system is modeled to produce cost estimates of alternative scenarios. These costs are then compared to determine the economic advantages or disadvantages of each scenario and, in this study, their impact on the economic competitiveness of nuclear power. Table 2 lists the modeling approaches used by the seven countries in developing baseline scenarios.

TABLE 2. Main assumptions in the development of national baseline scenarios

Country	*Study period*	*Tools (energy models) used*	*Level of energy demand modelling*	*Level of energy system modelling*	*Level of power system modelling*	*Cost basis*
Bulgaria	1997 – 2030	ENPEP for the energy system + IRP-Manager for the power system	Final energy	National energy system	IRP manager / by power units	$US of base year
China	1995 – 2030	MEDEE-S for demand projections + EFOM for the energy system	Final energy	National energy system	EFOM / by capacity additions	National currency of base year
India	1996 – 2036	National demand projections + MARKAL for the energy and power system	Useful energy	National energy system	MARKAL / by power units	$US of base year
Kazakhstan	1998-2030	National demand projections + ENPEP for the energy and power system	Final energy	National energy system	BALANCE by capacity additions	$US of base year
Pakistan	1997/98 – 2026/27	MAED for demand projections + ENPEP for the energy system + WASP for the power system	Final energy	National energy system	WASP / by power units	$US of base year
Russia	2000 – 2030	STRATEG (a national program package for energy and power system analysis)	Final energy	National energy system	STRATEG / by capacity additions	$US of 1997
Turkey	2000 – 2030	MAED for electricity demand projections + WASP for the power system	Electricity only	National power system	WASP / by power units	$US of base year

Taking ongoing restructuring into account, we chose the standard approach because, first, all the energy models in Table 2 are capable of modeling market features and are responsive to varying prices, the cost of capital, and other such market-driven cost differences, when selecting the most cost-effective development route for the energy system. Second, our purpose is to calculate the total investments needed regardless of who invests the money – whether private investors or state-owned companies. Although the form of capital ownership will ultimately affect the level of investments, that effect is more easily studied at the level of separate sectors and sub-sectors individually, for example the coal industry, the power sector, etc. While this project will not replace the need for such sectoral and sub-sectoral studies, our results will provide an important and useful background.

By themselves, the first-year baseline scenarios cannot of course answer our principal question – what is the impact of infrastructural requirements on the competitiveness of nuclear power? Rather baseline scenarios are a necessary first step. They provide a consistent basis against which we can subsequently compare alternative scenarios, with varying nuclear shares, policy assumptions, and cost estimates. Only by comparing a systematic range of scenario variations will we be able to draw conclusions about the link between nuclear development and infrastructural investment requirements. The project will focus of such scenario variations and comparisons during the second year.

4.2. Baseline Scenarios

The following sub-sections describe the national baseline scenarios for Bulgaria, Pakistan, and Russia. Bulgaria is an example of a country in economic transition that is highly dependent on imported energy. Russia is also a country in transition, but with extensive domestic energy resources. Pakistan is a typical developing country with expected high growth in energy demand. All three countries have nuclear power sectors.

4.2.1. Bulgaria

The following features of the Bulgarian energy system are particularly relevant.

- Bulgaria depends heavily on energy imports. About 60% of primary energy is imported. Understanding trends in energy imports and their correlation with the use of nuclear energy is therefore especially important.
- There are relatively large domestic coal deposits, but the coal is of poor quality and the most economic deposits are largely depleted. Increasing the domestic coal supply may require significant investments in coal mining.
- Approximately 40% of the electricity supply is generated by nuclear power. However, the future of nuclear energy is uncertain, in particular due to the possible early closure of several units at Kozloduy and construction interruptions at Belene.
- As in many other countries, the Bulgarian energy sector is considering expanding natural gas use. However, this may require new infrastructure developments (e.g., new gas pipelines), which would lead to both new infrastructure costs and increased import dependence.

Fig. 2 shows the structure of the primary energy supply in Bulgaria in 2000 and 2030 for the baseline energy scenario. Expected economic growth leads to a notable increase in primary energy (~40%) by 2030. Structurally, there is a visible increase in the shares of gas and oil. Some increase in nuclear energy is also indicated. These increases come largely at the expense of coal – while absolute coal use remains almost constant, its share of primary energy decreases from about 40% to 30%.

What this implies for energy imports is illustrated in Fig. 3. Import dependence increases significantly. Domestic energy production remains almost constant, and the increase in demand is covered entirely by increased imports. As a result, import dependence grows from 60% to 70% by 2030.

As shown in Fig. 4, capacity additions in the power sector include only natural gas and nuclear power plants, with nuclear providing most of the increase.

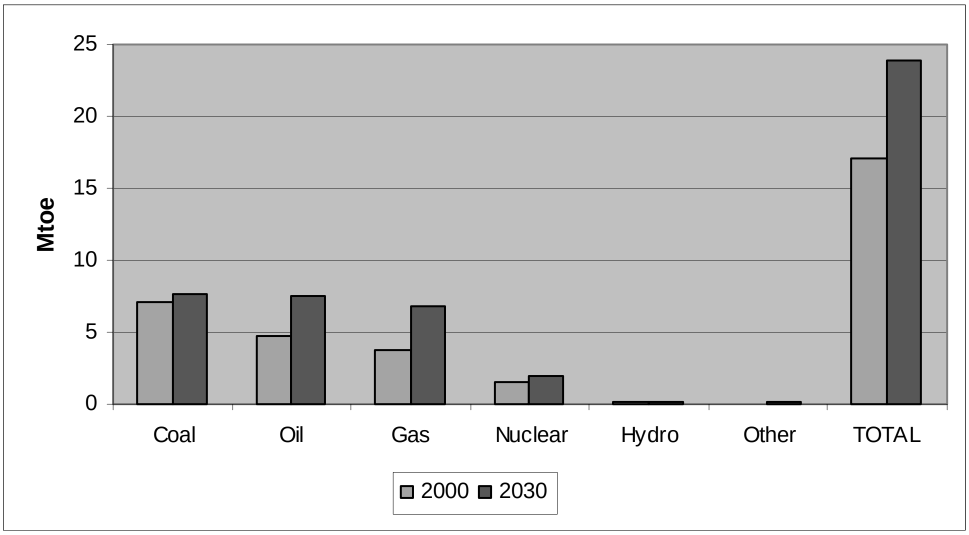

Figure 2. Bulgaria: primary energy supply in the baseline scenario (Mtoe)

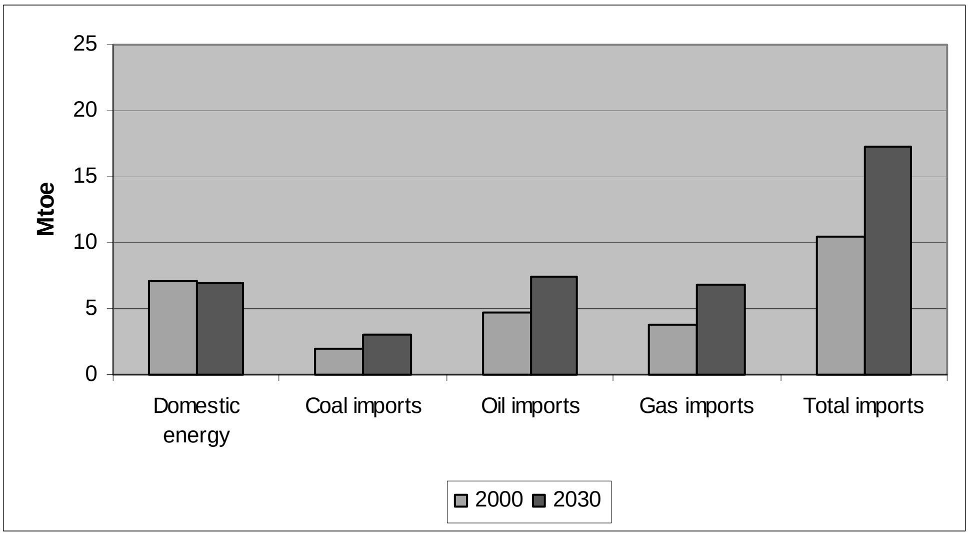

Figure 3. Bulgaria: energy imports in the baseline scenario (Mtoe)

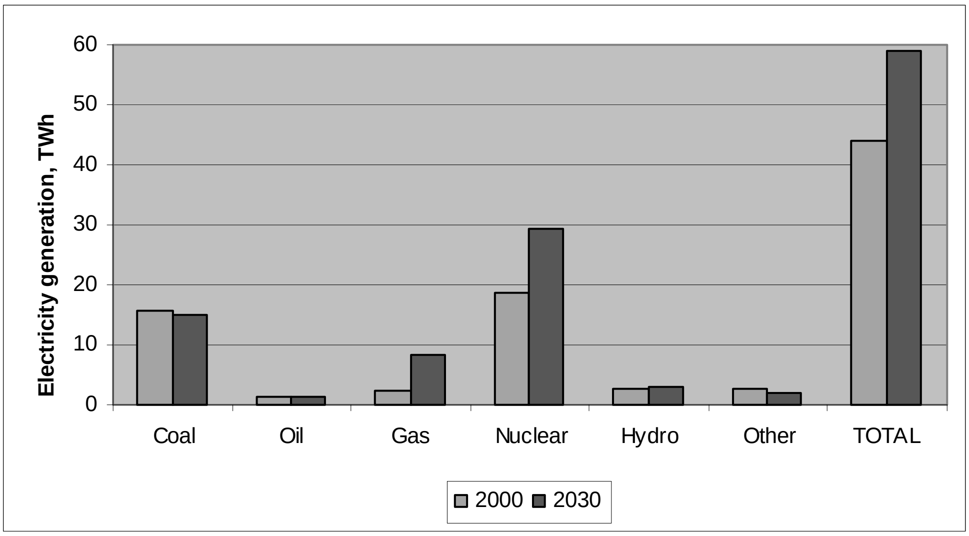

Figure 4. Bulgaria: electricity generation in the baseline scenario (TWh)

For the baseline scenario, existing domestic infrastructures – specifically domestic coal mines and natural gas pipelines – appear sufficient to support the expected growth in energy supply. Coal transportation requirements in Bulgaria are small as large coal-fired plants are usually located near the mines that supply their fuel. Because nuclear fuel is imported, no domestic nuclear infrastructure is required other than spent fuel management facilities. For these, a portion of electricity earnings (3% of the price of electricity) is contributed to a fund to cover expected costs.

Table 3 and Fig. 5 show the estimated total energy system costs for the baseline scenario, broken down into its principal components. As Fig. 5 illustrates, the most important cost component is energy imports. They account for about 45% of total costs. The share of the nuclear sector is about 18%, and the non-nuclear power sector accounts for 25%. The share of infrastructural investments in the domestic fuel supply is relatively small - only 12%.

Table 3. Bulgaria: Operation and Development Costs for the Baseline Scenario, $US million

Sector	Cost component	2001-2005	2006-2010	2011-2015	2016-2020	2021-2025	2026-2030	Present value at 10%
Coal	total domestic	1,613	1,658	1,618	1,549	1,191	1,197	2,972
	coal imports	296	344	367	366	393	409	632
	total coal	1,909	2,002	1,985	1,915	1,584	1,606	3,604
Oil	total domestic	529	557	586	617	652	690	1,066
	oil imports	4,251	4,980	5,732	6,598	7,624	8,858	9,863
	total oil	4,780	5,537	6,318	7,215	8,276	9,548	10,929
Gas	total domestic	80	93	87	94	98	162	165
	gas imports	2,632	2,995	3,371	3,820	4,561	5,624	5,960
	total gas	2,712	3,088	3,458	3,914	4,659	5,786	6,125
Nuclear part of power sector		2,017	4,075	4,018	5,607	3,438	3,981	6,237
Non-nuclear heat & power sector total (without fuel[7])		4,089	3,359	5,957	8,165	5,270	3,878	8,737
Domestic fuel sectors total		2,222	2,308	2,291	2,260	1,941	2,049	4,203
Fuel imports total		7,179	8,319	9,470	10,784	12,578	14,891	16,455
TOTAL		**15,507**	**18,061**	**21,736**	**26,816**	**23,227**	**24,799**	**35,632**

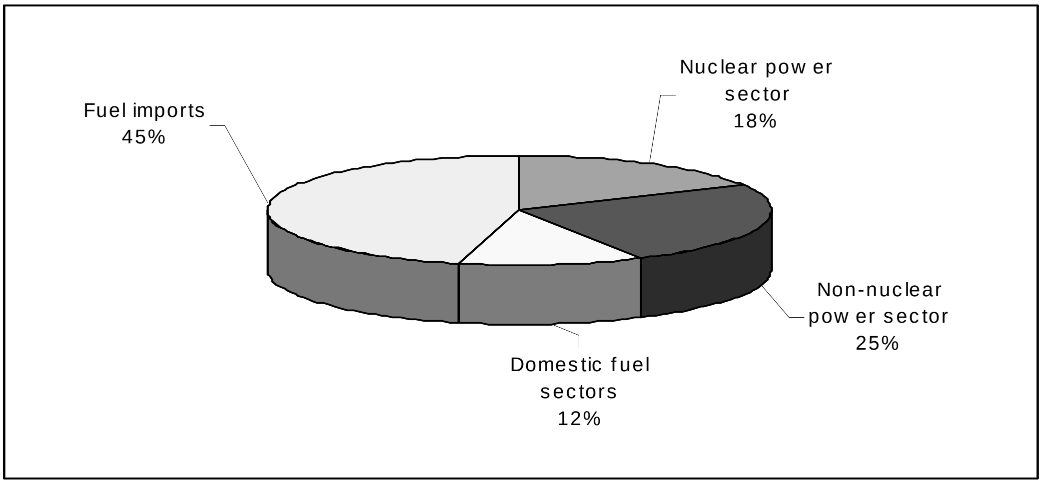

Figure 5. Bulgaria: energy system costs in the baseline scenario (present value at 10% discount rate)

The cost structure of the baseline scenario suggests that for Bulgaria the competitiveness of nuclear power may depend only marginally on the amount of infrastructural investments required to maintain *domestic* fossil fuel supplies. More important are likely to be the costs of energy imports, particularly natural gas and, to a lesser extent, imported coal. In particular, without nuclear power, energy imports would be higher, which is important not only in terms of costs, but also because it would increase Bulgaria's overall import dependence. This conclusion is reinforced by the large share of fossil fuel costs in Fig. 6.

The figure also shows that the costs of the nuclear sector amount to about 30% of total power system costs, while the share of electricity generated by nuclear is approximately 40%. This suggests that the nuclear sector is performing well economically and that any decrease in the nuclear contribution would increase overall system costs. However, such an inference has to

[7] The fuel costs of the power sector are not included to avoid double counting in the total.

be checked more carefully – for example, one cannot determine the role of cogeneration plants from Figures 5 and 6. The second year of the project will also further analyze infrastructural investments for existing coal mines and natural gas pipelines. As noted above, these investments appear to be relatively small, but several scenario variations will be examined to identify the importance of uncertainties concerning particularly pipeline performance and costs.

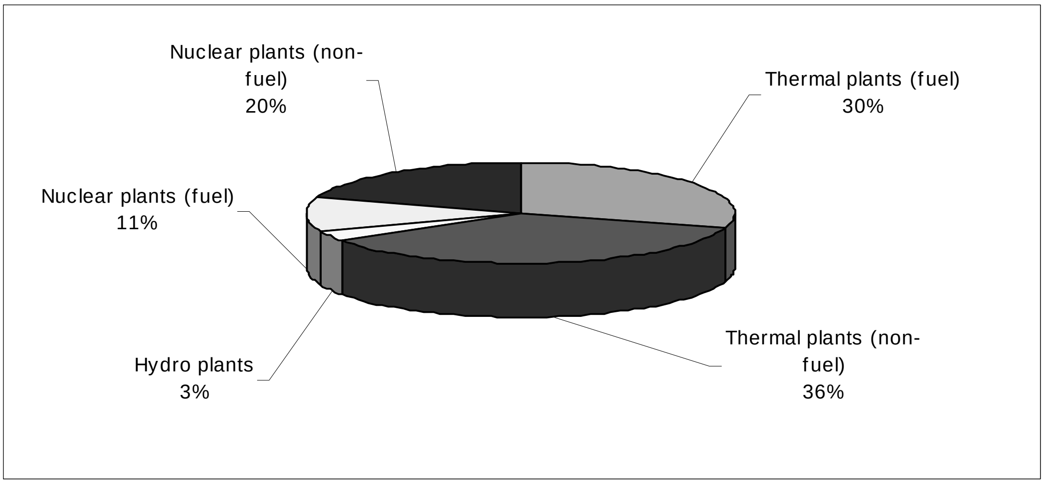

Figure 6. Bulgaria: power system costs in the baseline scenario (present value at 10% discount rate)

4.2.2. Pakistan

Pakistan's energy system has the following features:

- Despite recent progress, energy and electricity consumption per capita are still low in comparison with the world average; for the future, energy demand growth is expected to average 5-7% per year.
- Pakistan currently uses large amounts of imported oil and non-commercial energy. The cost of oil imports equals about 20% of export earnings and is a heavy burden on the national economy.
- There are huge domestic coal resources. However, over 95% of Pakistan's coal is in the recently discovered Thar field. Exploiting the Thar field will require substantial investments in mining and transportation infrastructure. Similar problems, although of a smaller scale, exist for the expansion of other domestic coal fields.
- Replacing non-commercial energy (mostly biomass) with commercial energy is a key problem. Although most energy models cover only commercially traded energy, the fact that the share of commercial energy in Pakistan is steadily growing is an important feature that must be kept in mind when developing model inputs and interpreting results.
- Nuclear energy has been introduced in Pakistan and remains a viable option. However, this study of infrastructural aspects of the energy system should identify additional nuclear advantages or disadvantages.

Fig. 7 shows the structure of the primary energy mix in the baseline scenario for Pakistan. The most remarkable feature of the system is the rapid growth in primary energy demand, approximately 5.4% per year. The energy supply becomes more diverse, shifting from predominantly gas and oil to a more balanced structure. By 2027 (30 years after the 1997 base year used by the Pakistani team), nuclear energy is of comparable importance to oil, coal, and gas.

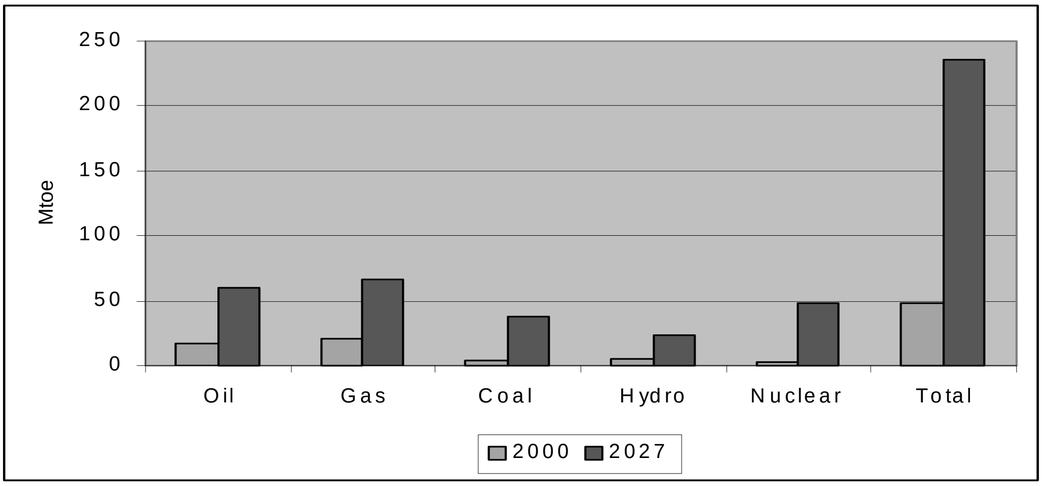

Figure 7. Pakistan: primary energy supply in the baseline scenario (Mtoe)

Fig. 8 shows significant changes in the pattern of energy imports. Imports constitute a steadily declining share of total energy use. By 2027, they make up only 20% of energy use, down substantially from today's value of 30%.

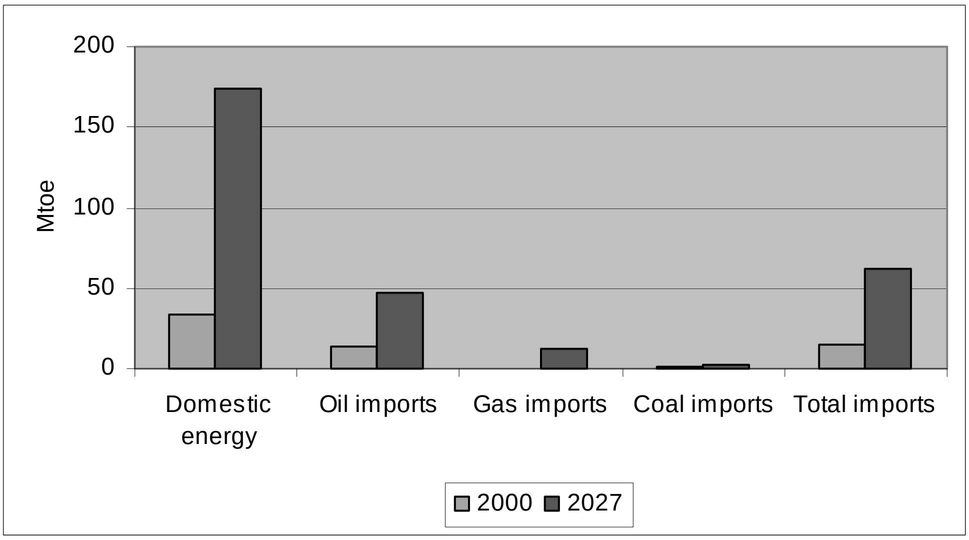

Figure 8. Pakistan: role of energy imports in the baseline scenario (Mtoe)

In the electric power system, generating capacities increase for all fuel options. The shares of hydropower, nuclear energy, and coal all increase, while that of oil and gas decreases. Nonetheless, as Fig. 9 illustrates, oil and gas remain the dominant fuels for power generation.

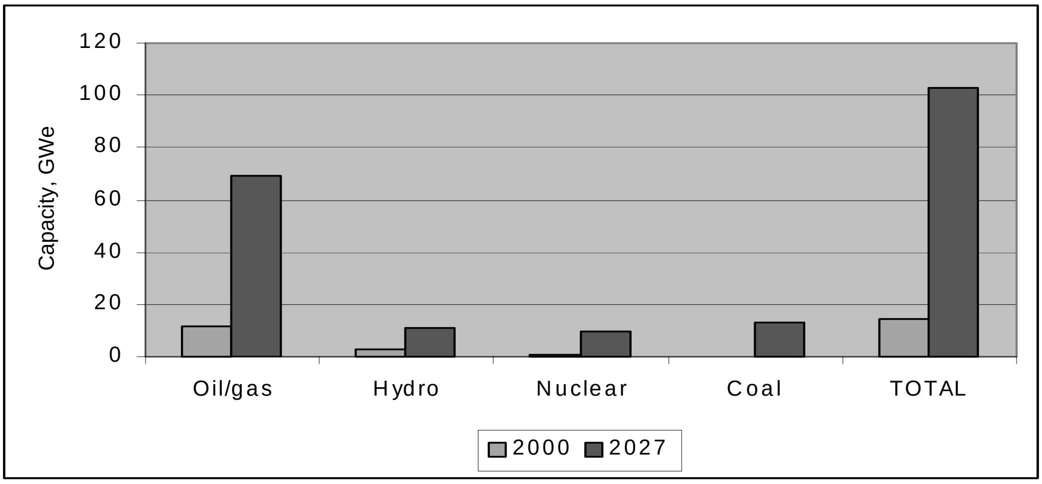

Figure 9. Pakistan: electricity generation capacity in the baseline scenario (GWe)

Preliminary energy system cost estimates for Pakistan are shown in Table 4 and Fig. 10. These indicate that that, contrary to the situation in Bulgaria, investments in the domestic infrastructure for supplying fossil fuels are essential in Pakistan. Their estimated present value outweighs the cost of energy imports, even though the latter are also large. This relative importance of domestic infrastructure reflects the increasing use of domestic energy resources shown in Fig. 8 above.

However, the preliminary estimates shown in the table include only capital costs for new construction, not capital costs associated with supporting existing infrastructural capacities. Nor do they yet include all energy transportation infrastructures. These missing costs, which will be estimated in the next stage of the project, should further increase the infrastructural share of total energy system costs.

For nuclear power, the preliminary numbers in Table 4 only include power plants plus other infrastructure costs that might be included in projected nuclear fuel costs. These figures will therefore be revisited in the next stage of the project to check for important infrastructural costs that may have been left out. Not surprisingly, Fig. 11 shows that, for nuclear power, fuel costs are small relative to power plant costs.

The preliminary picture for Pakistan is thus that infrastructure costs, for both nuclear power and its competition, are likely to have a relatively important impact on the competitiveness of nuclear power. In the next phase of the project we will try to quantify the magnitude of the impact as completely as possible.

Table 4. Costs of the Operation and Development of the Pakistan Energy System, $US million

Sector	Cost component	1998-2002	2003-2007	2008-2012	2013-2017	2018-2022	2023-2027	Present value at 10%
Coal	total domestic	1,949	1,557	3,639	12,224	14,186	18,452	8,401
	coal imports	344	443	595	870	393	1,024	994
	total coal	2,293	2,000	4,234	13,094	14,579	19,476	9,395
Oil	total domestic	4,447	5,615	6,112	8,046	11,669	14,094	11,667
	oil imports	9,180	10,220	11,922	16,081	22,849	37,656	23,171
	total oil	13,627	15,835	18,034	24,127	34,518	51,750	34,838
Gas	total domestic	8,775	13,061	19,367	20,435	30,056	37,287	27,767
	gas imports	0	797	0	0	1,287	9,551	1,118
	total gas	0	797	0	0	1,287	9,551	1,118
Nuclear part of power sector		104	160	5,401	4,239	9,965	11,036	4,346
Non-nuclear power sector total (without fuel[8])		2,596	8,401	14,704	13,026	10,060	10,191	14,032
Domestic fuel sectors total		15,171	20,233	29,118	40,705	55,911	69,833	47,835
Fuel imports total		9,524	11,460	12,517	16,951	24,529	48,231	25,283
TOTAL		27,395	40,254	61,740	74,921	100,465	139,291	91,496

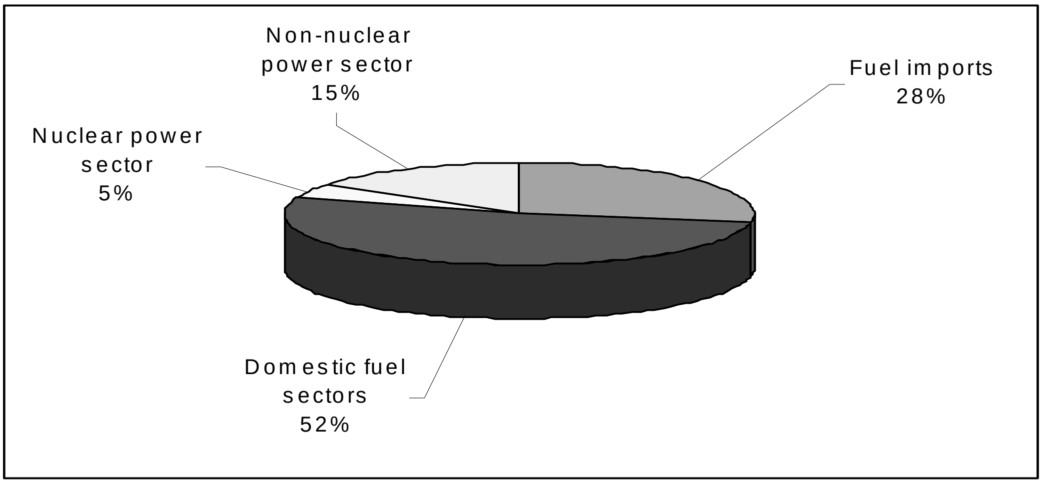

Figure 10. Pakistan: energy system costs in the baseline scenario (present value at 10% discount rate)

[8] The fuel costs of the power sector are not included to avoid double counting in the total.

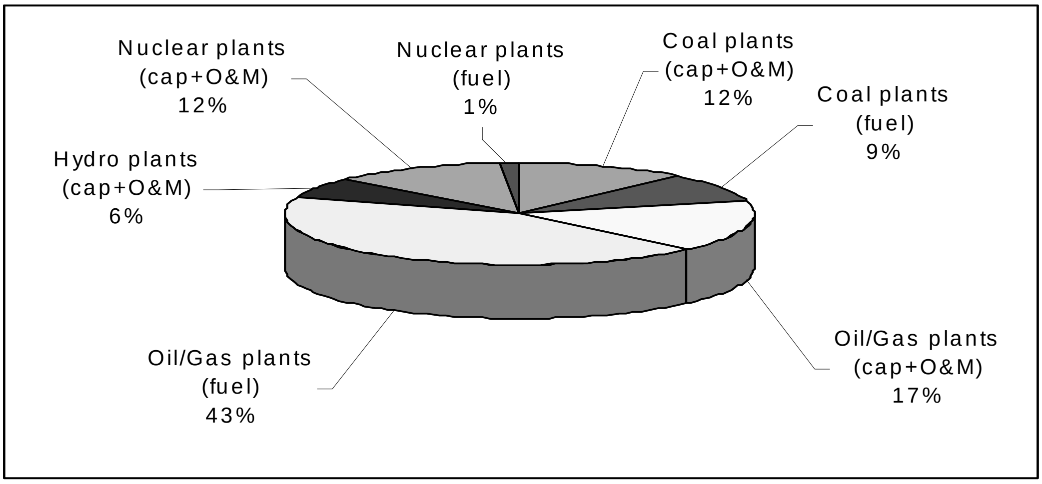

Figure 11. Pakistan: power system costs in the baseline scenario (present value at 10% discount rate)

4.2.3. Russia

For Russia, the following features have to be taken into account:

- Russia is a very large country with extensive energy resources. Most are concentrated in the Eastern part of the country. Because the country's main demand centers are in the West, energy infrastructures are extremely important. When analyzing the power system, regional interconnections are important to take into account.
- Russia exports a significant portion of its energy resources.
- The role of natural gas has been increasing in Russia, for both domestic use and export. The extent to which gas expansion will continue is a critical element in future projections.
- Nuclear energy is a mature technology in Russia, including all steps of both the open fuel cycle and the closed fuel cycle. The existing nuclear infrastructure represents an important asset beneficial to the nuclear sector.

Fig. 12 shows the development of the primary energy mix in Russia through 2020. Only gradual changes are projected, including a decrease in oil use and a slight increase in gas use. No dramatic progress is expected for renewable energy sources.

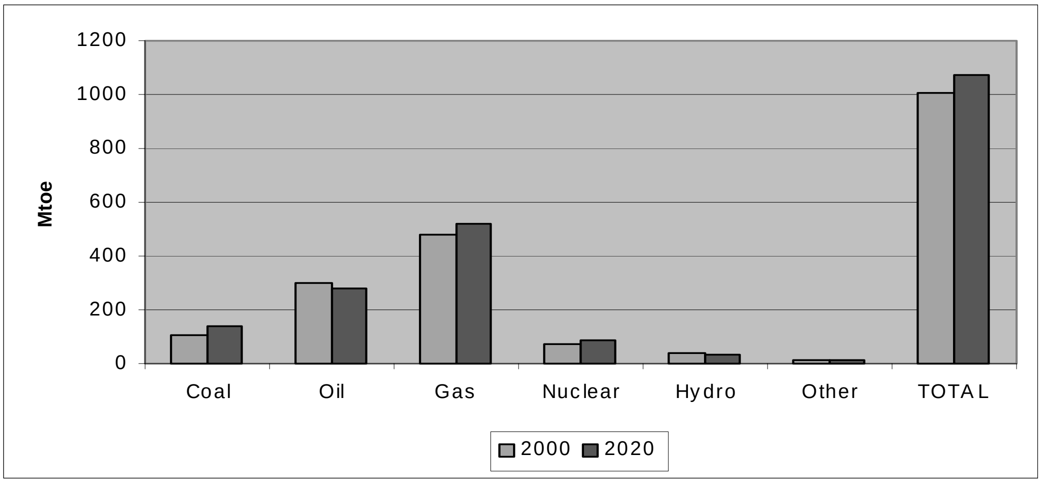

Figure 12. Russia: primary energy supply in the baseline scenario (Mtoe)

Russian energy exports are illustrated in Fig. 13. As in Fig. 12, there are no significant changes in the system except for slightly larger gas exports. The amount of exported energy is stable while domestic consumption increases (after 2005), reflecting the impact of economic recovery on energy demand.

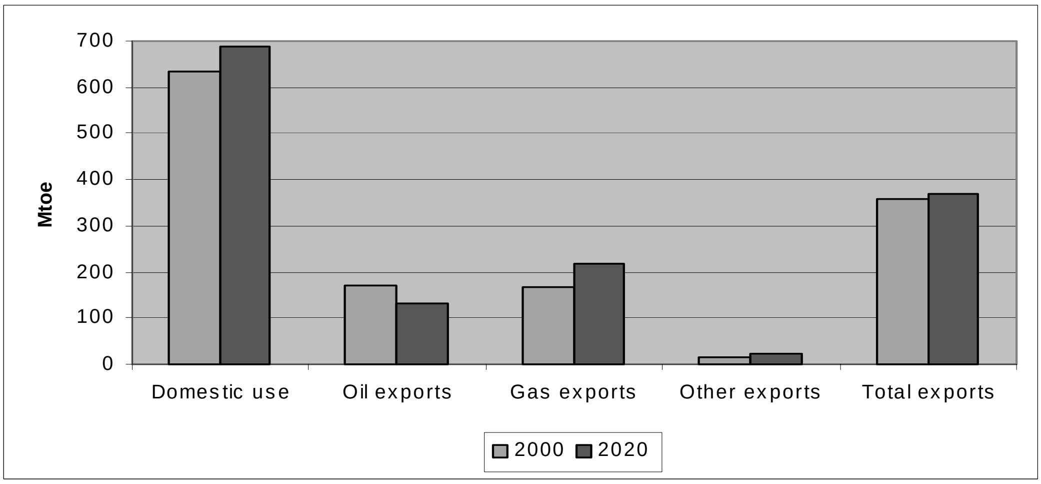

Figure 13. Russia: role of energy exports in the baseline scenario (Mtoe)

The structure of the power system is shown in Fig. 14. The most notable feature is the expected growth in the role of coal-fired generation, especially after 2015. Nuclear and gas-fired generation also grow but less sharply.

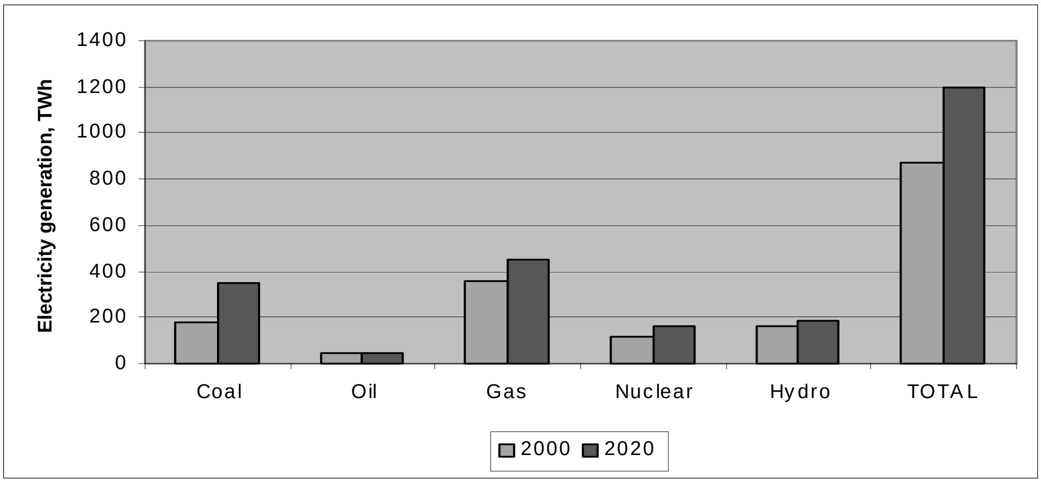

Figure 14. Russia: electricity generation in the baseline scenario (TWh)

Table 5 shows the full costs of the baseline scenario, including all exploration, investment, and operation costs. Fig. 15 shows the main components of the estimated present value in the last column of Table 5.

Table 5. Costs of the Operation and Development of the Russian Energy System, $US billion

Industry	Cost component	2001-2005	2006-2010	2011-2015	2016-2020	Present value at 10%
Coal sector	total	8.1	11.1	13.8	17.3	20.5
Oil sector	total	31.3	41.1	51.6	61.9	76.1
Gas sector	total	83.2	91.8	109.4	122.9	174.9
Power sector / thermal:	- existing plants	2.8	2.0	1.0	0.2	3.3
	- rehabilitation	1.1	32.5	47.3	29.8	36.1
	- new plants	2.1	3.2	11.3	26.2	14.7
	total	5.9	37.7	59.7	56.2	54.1
Power sector / hydro:	- existing plants	0.3	0.4	0.4	0.4	0.7
	- new plants	1.2	0.9	0.8	1.6	2.3
	total	1.6	1.3	1.2	2.1	3.1
Power sector / nuclear:	- existing plants	1.3	1.4	1.2	1.0	3.3
	- new plants	1.8	7.8	9.0	16.7	13.3
	- fuel cycle	0.5	0.6	0.6	0.7	1.1
	total	3.7	9.8	10.9	18.3	16.6
Power sector / transmission	total	3.3	5.8	7.8	7.1	9.4
Power sector	total	14.4	54.7	79.5	83.7	83.1
TOTAL	total	137.0	198.6	254.3	285.7	354.9

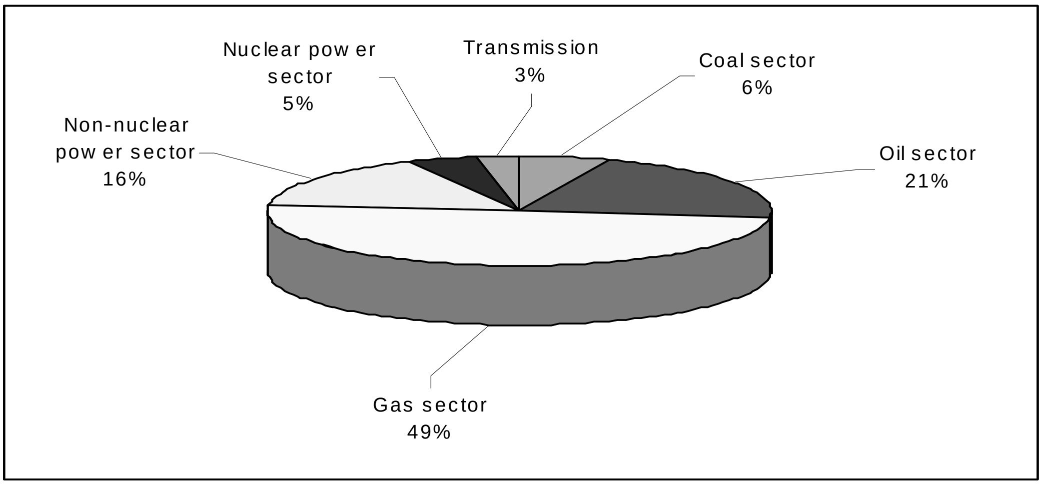

Figure 15. Russia: energy system costs in the baseline scenario (present value at 10% discount rate)

These cost estimates show the following:

- Two sectors account for about 75% of the present value: the gas sector (~50%) and the power sector (~25%). In terms of undiscounted costs, the combined share of these two sectors remains above 70% for each five-year period through 2020. Therefore, in the various scenarios to be studied in the next phase, we expect to pay particular attention to the interaction between the gas sector and the power sector.
- For all sectors, annual costs grow notably over the study period. This is driven less by demand growth, which is rather modest, than by rising investment requirements for equipment replacement.
- In the coal sector total costs are two times higher in 2016-2020 than in 2001-2005. In the gas sector they are about 50% higher. But in the power sector they are almost six times higher, emphasizing the importance of the power sector for the study's projections and comparisons of investments costs and infrastructure requirements.

As shown in Fig. 15, the nuclear sector accounts for 20% of the total present value of energy sector costs through 2020. As we move into the second phase of the project, we will analyze carefully potential changes in the interaction between the gas and power sectors that could lead to changes in nuclear investment requirements. In particular, if gas expansion requires greater infrastructure investments than in the baseline scenario, that may result in greater competitiveness for nuclear power and an increased nuclear share.

5. CONCLUSIONS AND FUTURE WORK

The first year of the project has laid out national baseline scenarios showing, for each country, one path for the long-term development of the national energy system. These baselines were developed to facilitate cost estimates associated with the support and development of national energy systems, including particularly energy sector infrastructure costs. Together the seven baseline scenarios establish a consistent basis for the project's subsequent core economic analysis.

The next step, to be carried out in the second and third years of the project, is to quantify the impact of infrastructural requirements on the competitiveness of nuclear power. This will be done through a scenario analysis. The scenarios will be designed to highlight possible links between required infrastructural investments (in both fossil fuel and nuclear infrastructures) and the share of nuclear power in the system. More specifically, the scenarios will include variations in such factors as the availability of domestic fossil fuel resources, the availability and costs of imported fuels, cost parameters for new nuclear power plants, the use of advanced nuclear fuel cycles, etc. Changes in the nuclear share from scenario to scenario will be compared to the corresponding changes in the structure and amount of infrastructural investments in the energy system. From these comparisons, we will draw conclusions concerning the link between infrastructural requirements and nuclear competitiveness.

The general outline of the scenario analysis is shown in Table 6. Although each country may interpret this outline slightly differently because of varying national priorities, the general direction presented in the table will be observed by all project participants.

First results of the scenario analysis are expected by end of 2001. The final results of the project will be available early in 2003.

Table 6. General scheme of scenario analysis

Scenario	Case	Meaning and expected result	Relevance
1: Baseline scenario	1-1: base case (with most probable values of uncertain parameters)	The "business-as-usual" structure of the energy system; the nuclear component is as most likely expected. With the calculated full set of energy system costs provides a basis for the subsequent comparison of scenarios.	Prepared by all countries in the 1st project year
	1-2: case of "nuclear phase-out":	The scenario allows determining the change in the system costs associated with a decision to phase-out nuclear energy; the resulting change in the infrastructural component of the system costs is to be shown in particular	Bulgaria, China, Pakistan, Russia
	1-3: case of strategic/forced nuclear development	The scenario allows estimating whether accelerated nuclear development could be beneficial with respect to the total system costs; the impact on infrastructural costs is to be shown. Such innovative nuclear developments as the closed fuel cycle, the introduction of fast reactors, and the use of thorium can be considered here as part of the scenario definition. The nuclear costs may increase in this case, but this may be outweighed by a decrease in the non-nuclear costs	India, Russia, Turkey
	1-4: case of improved nuclear economics	The scenario should consider nuclear development in case of reduced NPP capital costs (reflecting a technological breakthrough achieved by the nuclear industry). This can show infrastructural gains for the whole energy system due to a technological breakthrough leading to significant reductions of NPP capital costs. The possible assumptions are: the new, cheap nuclear project is ready 2005; the deployment can start in 2010; the new project is characterized by lower capital costs, e.g., -(30-50%) of capital costs of current nuclear designs.	Bulgaria, China, India, Kazakhstan, Pakistan, Turkey
	1-5: case of more conservative assumptions about price/availability of domestic coals	The scenario should use more pessimistic assumptions on the availability of domestic coals. The limited availability would lead to increased infrastructure costs (more expensive mines, longer lead times) in the coal sector. This will allow seeing the link between the nuclear share and the coal infrastructures.	China, India, Pakistan, Russia, Turkey
	1-6: case of more conservative assumptions about price/availability of domestic gas	The scenario should use more pessimistic assumptions on the availability of domestic gas. The limited availability would lead to increased infrastructure costs (longer pipelines, more expensive gas fields) in the gas sector. This will allow seeing the link between the nuclear share and the gas infrastructures.	China, Russia
	1-7: case of expensive imported fossil fuels	The scenario should show the possible variation of the costs in the case of more expensive imports of fossil fuels. More expensive imports would lead to a different mix of imports and domestic production, which affects both the costs of domestic energy infrastructures and the nuclear share in the power system.	Bulgaria, India, Pakistan, Turkey
	1-8: case of aggressive renewables	The scenario should show the cost impact of policies pursuing accelerated introduction of renewable energy sources. It can show, in particular, whether a development based on renewables could lead to lower infrastructural costs than the use of nuclear energy.	India
	1-9: case of limitations on energy imports	The scenario should reflect the impact of possible constraints on energy imports on the system costs (the infrastructural component in particular) and the share of nuclear energy.	Turkey
	1-10: case of CO_2 limitations	The scenario should reflect the impact of the possible constraints on the use of fossil fuels due to Kyoto-type agreements on the system costs, the infrastructural component in particular.	Bulgaria, Kazakhstan, Turkey, Russia
2	2-1, 2-2, … for an alternative demand projection	Similar to the cases for baseline scenario	To be considered in all countries

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